Improvement in the Spread Spectrum System in DSSS, FHSS, AND CDMA

Gowrilakshmi Ponuratinam, Bhumika Patel, Syed S. Rizvi Khaled M. Elleithy
Computer Science and Engineering Department, University of Bridgeport, Bridgeport, CT 06605
{gponurat, bhumikpa, srizvi, elleithy}@bridgeport.edu

Abstract - *In this paper, we introduce spread spectrum links that can be used to overcome intentional jamming. The problem of communicating in the presence of jamming is very much akin to the problem of communicating over fading channels. Hence, by finding out how to defeat jamming by spread spectrum will also reveal how to overcome fading. Today, spread spectrum links are also used in many civilian systems to overcome non-intentional jamming (or interference), and the report is concluded with an overview of current commercial spread spectrum systems. In addition to the traditional coherent spread-spectrum systems, the definition of an ideal modified version is introduced and this model is analyzed from an information theoretic viewpoint. The project uses a simple point-to-point communication system with fully synchronized transmitter and receiver in a simple channel with white Gaussian noise and arbitrary jamming signal. We prove that in traditional systems the channel converges to a Gaussian noisy channel in the limit in the case of almost any jamming signal, and in our new ideal modified system the channel converges to a white Gaussian noisy channel in the limit in the case of any jamming signal when the processing gain goes to infinity.*

I. INTRODUCTION

Spread-spectrum techniques are methods by which energy generated in a particular bandwidth is deliberately spread in the frequency domain resulting in a signal with a wider bandwidth.

Spread-spectrum telecommunications is a signal structuring technique that employs direct sequence, frequency hopping or a hybrid of these, which can be used for multiple access and/or multiple functions. This technique decreases the potential interference to other receivers while achieving privacy. Spread spectrum generally makes use of a sequential noise-like signal structure to spread the normally narrowband information signal over a relatively wideband (radio) band of frequencies. The receiver correlates the received signals to retrieve the original information signal. Originally there were two motivations: either to resist enemy efforts to jam the communications (anti-jam, or AJ), or to hide the fact that communication was even taking place, sometimes called low probability of intercept (LPI).

Frequency-hopping spread spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channel, using a pseudorandom sequence known to both transmitter and receiver. Spread-spectrum signals are highly resistant to narrowband interference. The process of re-collecting a spread signal spreads out the interfering signal, causing it to recede into the background.

Code division multiple access (CDMA) is a channel access method utilized by various radio communication technologies. CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code) to allow multiple users to be multiplexed over the same physical channel. By contrast, time division multiple access (TDMA) divides access by time, while frequency-division multiple access (FDMA) divides it by frequency. CDMA is a form of “spread-spectrum” signaling, since the modulated coded signal has a much higher data bandwidth than the data being communicated.

A. Problem Identification

Let us study a simple example to illustrate the basic concepts and ideas of spread spectrum. Let the average received communication signal power and received jamming signal power is denoted by S and J, respectively. We ignore any other interference, such as thermal noise, at this stage. The basic question is “How can we communicate reliably even when $J >> S$?”Actually, we know the answer from basic communication theory. We know that we can communicate over a channel disturbed by additive white Gaussian noise (an AWGN channel). White noise has infinite power, but since the power is spread over an infinite number of signal space dimensions (or infinite bandwidth), the power per signal space dimension is finite. Hence, by concentrating the transmitter power to a finite-dimensional signal space, we can gain a power advantage over the noise.

The same idea is used in a jamming situation. However, we must make the choice of signal space dimensions used for transmission a secret for the jammer. Otherwise, the jammer can concentrate its power to the same dimensions, and nothing is gained. This implies that we need to hide the transmitted signal in a space with many more dimensions than what is needed for the transmitted signal.

The different types of jamming problems identified in the Spread Spectrum are as follows:

i) DS-SS and Broadband Continuous Noise Jamming.

ii) DS-SS and Narrowband Jamming.

iii) Plus Jamming.

iv) Broadband Jamming.

v) Partial- Band Noise Jamming.

II. RELATED WORK

As explained in the problem identification, the definition of Jamming and the cause and effect of Jamming, the dimensionality of a signal space depends on duration and bandwidth of the signals in the space. If the spread spectrum bandwidth is *Wss.* i.e. the transmitted signal must reside in a frequency band of width *Wss* Hz. If the data rate is *Rb* = 1/*Tb*, then the transmission of a packet of *P* information bits will take approximately *Tp* seconds, where

$$Tp= PTb= P/ Rb$$

The set of all signals that are time-limited to *Tp* seconds and band limited to *Wss* Hz spans a signal space of (approximately) *Np* = 2*WssTp* dimensions. Hence, the number of dimensions available for the transmission of one information bit is

$$Nd= Np/P= 2(Wss/ Rb)$$

A characteristic of a spread spectrum system is that ratio *Wss/Rb* is very large. The larger the ratio the more resistant to jamming the system can be made. The number *Wss/Rb* is often called the processing gain. If the jammer has no idea which subset of the *Nd* dimensions that is used for the transmission, it may decide to spread its

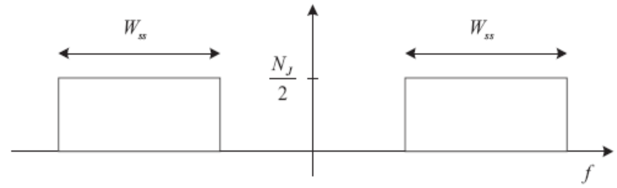


Figure 1: Power spectral density of a broadband noise jammer

.

power equally over all dimensions. The spectral height of the jamming signal, see Figure 1 is denoted *NJ/*2, where

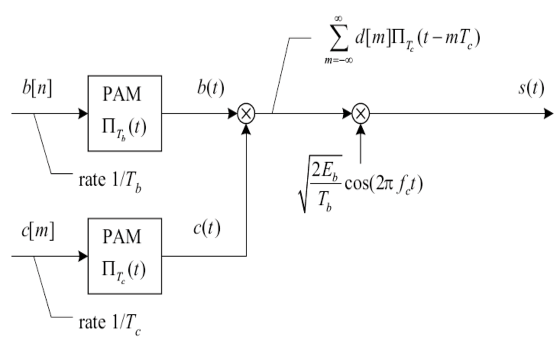
$$J = 2\ W_{ss}\ (NJ/2) = W_{ss}\ (NJ)$$

This type of jamming is called broadband and now we will assume that the noise is Gaussian. The broadband noise jamming is benign. To quantify the effect of jamming, consider the effect on a binary phase-shift keying. The bit error probability is

$$Pb = Q\ (\sqrt{}\ 2\ Eb/NJ)$$

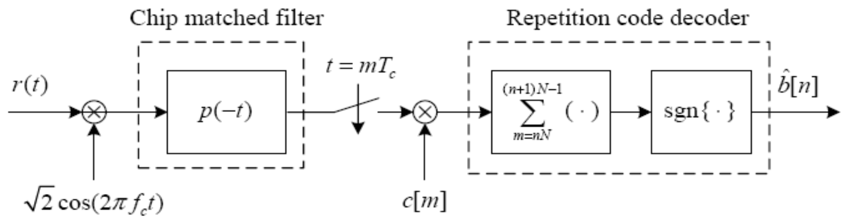
Where *Eb* = *STb* = *S/Rb* is the received energy per information bit and Q(x) = 1/√2∏ ∫ *e*−*t*2/2 dt.

The error probability is decreasing exponentially with Eb/NJ, since Eb/NJ= S Wss/J Rb. We can reach any bit error probability for any jammer-to-signal power ratio, *J/S*, by making the processing gain large enough. However, we should remember that we have



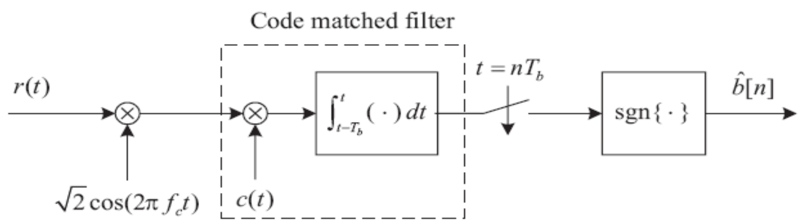
Modulator for DS-SS with BPSK modulation and rectangular chip waveforms.

Figure 2: Modulator for DS-SS with BPSK modulation and rectangular chip waveforms.



Demodulator for DS-SS with BPSK modulation with an arbitrary chip waveform $p(t)$.)

Figure3: Demodulator for DS-SS with BPSK modulation with an arbitrary chip waveform p (t)



Demodulator for DS-SS with BPSK modulation with rectangular chip waveform.

Figure 4: Demodulator for DS-SS with BPSK modulation with rectangular chip waveform

reached this conclusion under idealized circumstances. For instance, if the jamming causes the synchronization or front-end electronics or processing to fail, then this will effectively disrupt the communication.

III. Proposed Solution For Direct Sequence Spread Spectrum

Consider an ordinary un-coded BPSK. The transmitted signal would be

$$s\ (t) = \sqrt{2\text{Eb}} \cos\ (2\pi \text{fct})$$

summation with upper bound ∞ and lower bound n= -∞ for b[n]p (t − nTb). Where Eb is the energy per information bit, fc is the carrier frequency, b[n] ∈ {±1} is the nth information bit, p(t) is the unit-energy pulse shape, and the data rate is Rb = 1/Tb. The bandwidth of s(t) is determined by the pulse shape and data rate. For the special case of rectangular chip pulses, we can rewrite the transmitted signal as:

s (t) = √ 2Eb/Tb cos (2∏fc t) b (t) c (t)

where the data signal b (t) is defined as

b (t) = summation with upper bound ∞ and lower bound n= -∞ (*b*[*n*]Π *Tb* (*t* − *nTb*)), and the scrambling waveform be defined as

c (t) = summation with upper bound ∞ and lower bound m= -∞(c[*m*]Π *Tc* (*t* − *mTc*)

From the figures given below, when we take up and rectangular chip pulse the bit probability error is minimized if the received signal is equal to the transmitted signal plus white Gaussian noise. Hence, if the jammer waveform is Gaussian noise that is spectrally white over the system bandwidth and if we ignore any other interference the bit error probability is Pb= Q (√ 2Eb/Nj). Assuming that the channel also adds white Gaussian noise with power spectral density No/2, and then the resulting bit error probability is Pb= Q (√2 (Eb/Nj+No)).Note that the processing gain only affects NJ=J Rb/Wss. Hence, the bandwidth expansion does not help at all to combat the white channel noise. However by replacing the repetition code with a better channel code, we can combat both the jamming and the channel noise more efficiency.

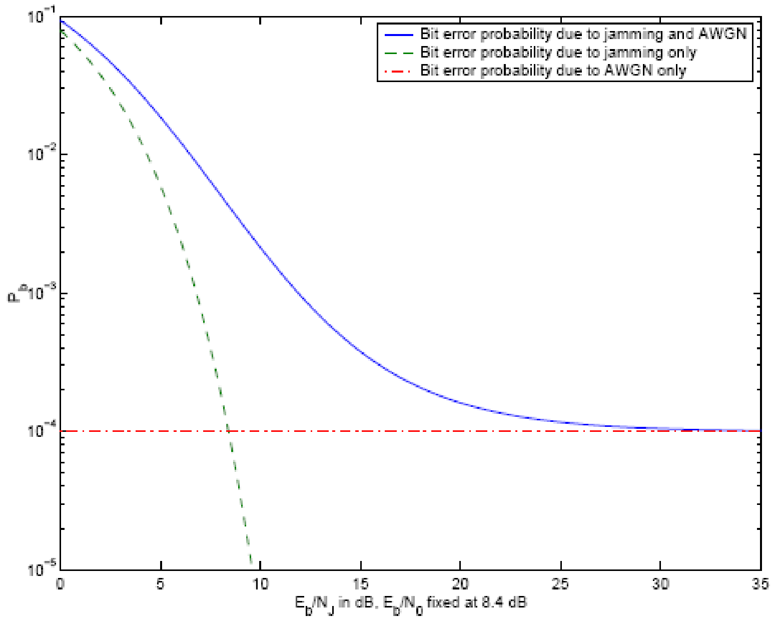
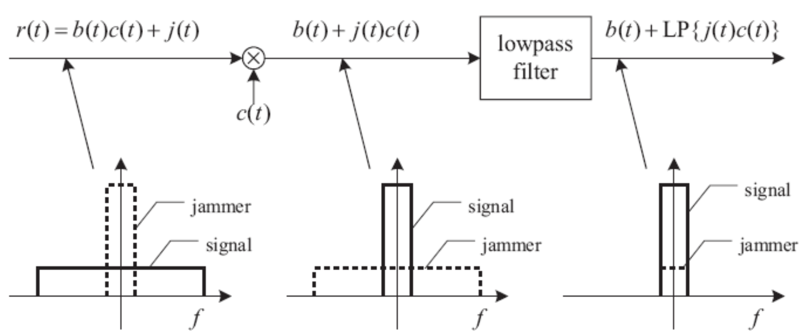


Figure 5: Bit error probability for DS-SS with BPSK modulation over an AWGN channel with Eb/No=8.4dB and with broadband noise jamming of varying power

From figure 2 and 4, DS-SS is more effective against narrowband jamming and interference. Suppose the jamming signal is a pure cosine at carrier frequency fc with the power J and phase Θ, .i.e. $j(t) = \sqrt{2J}\cos(2\prod fc\, t + \Theta)$ contribution from the jammer to the input to the integrator block figure 2 is

$j(t)\sqrt{2J}\cos(2\prod fc\, t + \Theta) =$
$\sqrt{J}c(t)\, 2\cos(2\pi fct + \theta)\cos(2\pi fct)$
$= \sqrt{J}c(t)[\cos(\theta) + \cos(4\pi fct + \theta)]$
$= \sqrt{J}c(t)\cos(\theta) + \sqrt{J}c(t)\cos(4\pi fct + \theta).$



Despreading operation in the presence of narrowband jamming. The plots show the power spectral densities at various points in the despreading circuit (double frequency terms are neglected in this figure).

Figure 6: Despreading operation in the presence of narrowband jamming.

The second term in the equation above will have its power centered on twice the carrier frequency and since the integrator is a low-pass filter. The first term has its power centered on DC and is spread over the entire system bandwidth. The integrator is a low-pass filter with a cut-off frequency of approximately 1/Tb Hz only a fraction of the jammer power will remain after the integrator. The same arguments can be made for a more general narrowband jamming signal. The receiver will spread the power of the jamming signal over a span approx. the entire system bandwidth, and the integrator will lowpass filter the spread jamming signal. So, only a small amount of the jamming power will effect the decision on the information bits. Finally the desired signal component will be dispread by the receiver.

B. *Pulse Jamming*

A broadband pulsed noise jammer transmits noise whose power is spread over the entire system bandwidth. However, the transmission is only on for a fraction ρ of the time (i.e., ρ is the duty cycle of the jammer transmission and $0 < \rho \leq 1$). This allows the jammer to transmit with a power of J/ρ when it is transmitting (remember that J is the average received jammer power), and the equivalent spectral height of the noise is $NJ/2\rho$. To make a simple analysis of the impact of a pulsed jammer we start by assuming that the jammer affects an integer number of information bits. That is, during the transmission of a certain information bit, the jammer is either on (with probability ρ) or off (with probability $1 - \rho$). Furthermore, if we assume that the jammer waveforms is Gaussian noise and ignore all other noise and interference, the bit error probability for a DS-SS system with BPSK modulation is

$$Pb = \rho\ Q(\sqrt{(2Eb/Nj\ )\ \rho}$$

For a fixed value Eb/Nj, the worst case jammer duty cycle can be found by:

$$\rho wc = \{\ 0.769/(Eb/Nj);\ Eb/Nj > 0.769$$

1; Eb/Nj< 0.769 and the corresponding bit error probability is:

$$Pb = \begin{cases} 0.083/(Eb/Nj); & Eb/Nj > 0.769 \\ Q(\sqrt{Eb/Nj}); & Eb/Nj < 0.769 \end{cases}$$

The above is explained in figure 7, if the jammer uses the worst-case duty cycle, then the bit error probability is only decaying as $1/(Eb/NJ)$ rather than exponentially in Eb/NJ. As seen from the figure, to reach $Pb = 10{-}4$ we have to spend almost 21 dB more signal power compared to case for a broadband continuous noise jammer.

C. *FHSS Analysis*

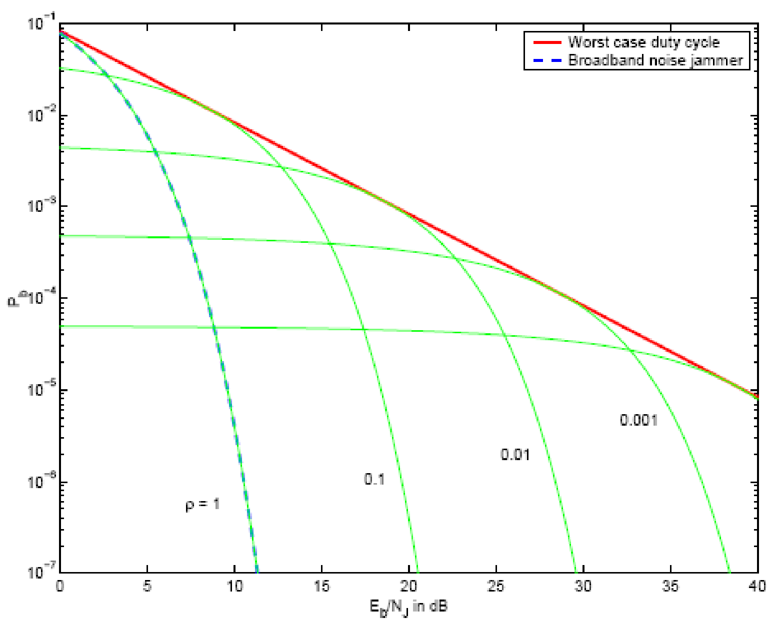


Figure 7: Bit error probability for BPSK-modulated DS-SS with pulsed noise jamming with duty cycle ρ

The larger the system bandwidth, the shorter the pulses must be. Hence, for DS spread spectrum, *Wss* is limited to few hundred MHz due to hardware constraints. This implies that the processing gain is also limited. Moreover, the system bandwidth must be contiguous. Both these limitations can be avoided by using a frequency-hopped spread spectrum (FH-SS) system. The baseband signal denoted by

$$s(t)= x(t)\sqrt{2}\cos(2\pi f_k t +\theta_k),\ k T_h \leq t < (k + 1)T_h$$

where $1/T_h$ is the frequency hopping rate and f_k and θ_k is the carrier frequency and phase after the *k*th hop.

D. Broadband Jamming

The most benign form of jamming is broadband non-pulsed noise jamming. For uncoded binary FSK with non-coherent detection, the resulting bit error probability is:

Pb =1/2 e power –Eb/2Nj

where Nj=J/Wss.

A jammer that uses partial-band noise jamming will concentrate its power to a bandwidth ρWss, where ρ is the frequency domain duty cycle ($0 < \rho \leq 1$). The jammer signal is Gaussian noise with a flat power spectral density over the jammed bandwidth, i.e., in the jammed band the power spectral density is J/2Wss ρ= Nj/2 ρ. If we assume that the jammed bandwidth is placed such that all signal alternatives used for a certain symbol are either jammed or not jammed, then the probability that a certain symbol will be jammed is ρ. The resulting bit error probability for BFSK with non-coherent detection is then
Pb = (1 − ρ) × 0 + ρ1/2exp (-Eb ρ/2Nj)
= ρ/2exp (-Eb ρ/2Nj). The worst duty cycle would be ρwc={ 2/(Eb/Nj);Eb/Nj>2 & 1;Eb/Nj<=2, the worst bit error probability will be Pb,wc = {1/(eEb/Nj; Eb/Nj>2 & ρ/2exp(-Eb ρ/2Nj) ;Eb/Nj<=2

IV. CONCLUSION

The Spread Spectrum System has a diverse application over non-military work like underwater communication, wireless local loop system, wireless local area networks, cellular system, satellite communication and ultra wideband systems. Spread Spectrum is also used in wired application in e.g. power-line communication and has been proposed for communication over cable- TV network and optical fiber system. Finally, spread spectrum techniques have been found to be useful in ranging e.g., radar, and navigation (GPS).

REFERENCE

1) google.com-Chalmers "Introduction to Spread Spectrum System", ERIK STRÖM, TONY OTTOSSON, ARNE SVENSSON *Department of Signals and Systems* CHALMERS UNIVERSITY OF TECHNOLOGY

2) Robert A. Scholtz. "The origins of spread spectrum communications." *IEEE Transactions on Communications*, vol. 30, no. 5, pp. 822–854, May 1982. (Part I).

3) Robert A. Scholtz. "Notes on spread-spectrum history." *IEEE Transactions on Communications*, vol. 31, no. 1

4) Marvin K. Simon, Jim K. Omura, Robert A. Scholtz, and Barry K. Levitt. *Spread Spectrum Communications Handbook*. McGraw-Hill, revised edition, edition, 1994.

5) Robert C. Dixon. *Spread Spectrum Systems with Commercial Applications*. John Wiley and Sons, third edition, 1994.

6) Denny Radford. "Spread spectrum data leap through AC power wiring." *IEEE Spectrum*, vol. 33, no. 11, pp. 48–53.